CSC 4304 - Systems Programming
Fall 2008

LECTURE - XI

SIGNALS - II

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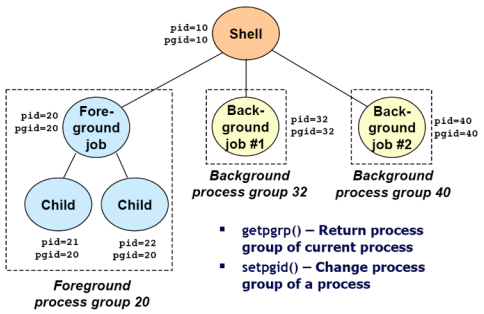
Process Groups

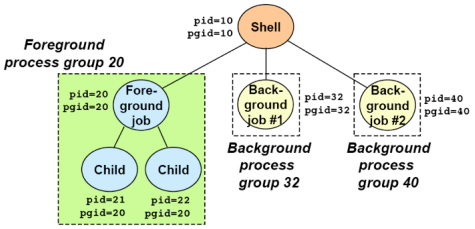
- **Every process belongs to exactly one process group.**



- **getpgrp() – Return process group of current process**
- **setpgid() – Change process group of a process**

Sending Signals

- **Sending signals from the keyboard**
  - Typing **ctrl-c** (**ctrl-z**) sends a **SIGINT** (**SIGTSTP**) to every job in the foreground process group.
    - SIGINT: default action is to terminate each process.
    - SIGTSTP: default action is to stop (suspend) each process.



Signals from Keyboard

The most common way of sending signals to processes is using the keyboard:

- Ctrl-C: Causes the system to send an `INT` signal (`SIGINT`) to the running process.
- Ctrl-Z: causes the system to send a `TSTP` signal (`SIGTSTP`) to the running process.
- Ctrl-\:causes the system to send a `ABRT` signal (`SIGABRT`) to the running process.

Signals from Command-Line

- The *`kill`* command has the following format:

  `kill [options] pid`

  – `-l` lists all the signals you can send
  – `--`*`signal`* is a signal number
  – the default is to send a `TERM` signal to the process.
- The `fg` command will resume execution of the process (that was suspended with Ctrl-Z), by sending it a `CONT` signal.

```
$ kill 10231        // SIGTERM : default signal
$ kill -9 10231     // SIGKILL
```


Signals from a Process

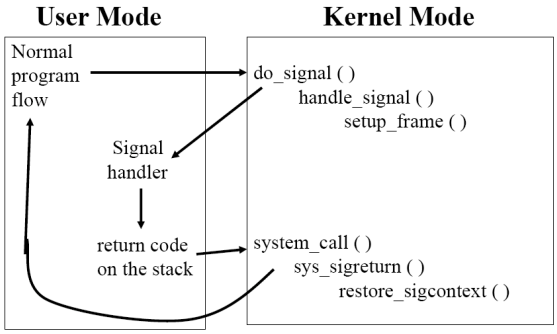
- **int kill(pid_t pid, int sig)**
  - Can be used to send any signal to any process group or process.
    - **pid** > 0, signal **sig** is sent to **pid**.
    - **pid** == 0, **sig** is sent to every process in the process group of the current process.
    - **pid** == -1, **sig** is sent to every process except for process 1.
    - **pid** < -1, **sig** is sent to every process in the process group -**pid**.
    - **sig** == 0, no signal is sent, but error checking is performed.

- `raise(signo)` causes the specified signal to be sent to the process that executes the call to raise.

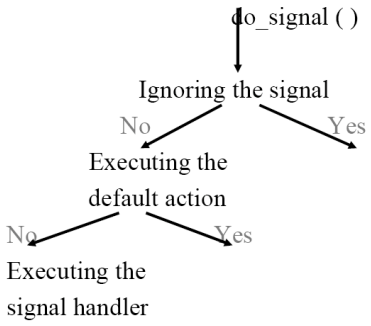
Sending Signals (Example)

```
void fork12(int N) {
  pid_t pid[N];
  int i, child_status;

  for (i = 0; i < N; i++){
    pid[i] = fork();
    if (pid[i] == 0){
       if (i==2) signal(SIGINT, SIG_IGN);
       while(1); /* Child infinite loop */
    }
   else
     if (pid[i]>0) printf("Child process %d is created.\n", pid[i]);
  }

  /* Parent terminates the child processes */
  for (i = 0; i < N; i++) {
    printf("Killing process %d..\n", pid[i]);
    kill(pid[i], SIGINT);
  }

  /* Parent reaps terminated children */
  for (i = 0; i < N; i++) {
    pid_t wpid = wait(&child_status);
    if (WIFEXITED(child_status))
      printf("Child %d terminated with exit status %d!\n",
         wpid, WEXITSTATUS(child_status));
    else
      printf("Child %d terminated abnormally\n", wpid);
  }
}
```


Catching the Signal



Actions on Signal



Non-Catchable Signals

- Most signals may be caught by the process, but there are a few signals that the process cannot catch, and cause the process to terminate.
  - For example: `KILL` and `STOP`.
- If you install no signal handlers of your own the runtime environment sets up a set of default signal handlers.
  - For example:
    - The default signal handler for the `TERM` signal calls the `exit()`.
    - The default handler for the `ABRT` is to dump the process's memory image into a file, and then exit.

Default Actions

- Abort – terminate the process after generating a dump
- Exit – terminate the process without generating a dump
- Ignore – the signal is ignored
- Stop – suspends the process
- Continue – resumes the process, if suspended

Signal Semantics

- A signal is pending if it has been sent but not yet received.
  - There can be at most one pending signal of any particular type.
  - Signals are not queued!
- A process can block the receipt of certain signals.
  - Blocked signals can be delivered, but will not be received until the signal is unblocked.
  - There is one signal that can not be blocked by the process. (SIGKILL)
- A pending signal is received at most once.
  - Kernel uses a bit vector for indicating pending signals.

Implementation

- Kernel maintains **pending** and **blocked** bit vectors in the context of each process.
  - **pending** – represents the set of pending signals
    - » Kernel sets bit k in **pending** whenever a signal of type k is delivered.
    - » Kernel clears bit k in **pending** whenever a signal of type k is received.
  - **blocked** – represents the set of blocked signals
    - » Can be set and cleared by the application using the **sigprocmask** function.

Receiving Signals

- **Handling signals**
  - Suppose kernel is returning from exception handler and is ready to pass control to process p.
  - Kernel computes **pnb** = **pending** & ~**blocked**
    - The set of pending nonblocked signals for process p
  - if (**pnb** != 0) {
    - Choose least nonzero bit k in **pnb** and force process p to receive signal k.
    - The receipt of the signal triggers some action by p.
    - Repeat for all nonzero k in **pnb**.

    }
  - Pass control to next instruction in the logical flow for p.

Overlapping Signals

- SIGY interrupts SIGX
  - ex: phone then door
  - When you press CTRL-C then CTRL-\, the program first jumps to inthandler, then to quithandler, then back to inthandler, then back to main loop.
- SIGX interrupts SIGX
  - ex: two people coming to your door
  - Three ways this can be handled:
    1. Recursively call the same handler
    2. Ignore the second signal, like a phone without call waiting
    3. Block the second signal until done handling the first
  - Original systems used method 1, though method 3 is safest.
- Interrupted System Calls
  - receiving a signal while waiting for input

Example from Last Lecture

```
main(int ac, char *av[])
{
        void    inthandler(int);
        void    quithandler(int);
        char    input[100];

        signal( SIGINT,  inthandler );    //set trap
        signal( SIGQUIT, quithandler );   //set trap

        do {
                printf("\nType a message\n");
                if ( gets(input) == NULL )
                        perror("Saw EOF ");
                else
                        printf("You typed: %s\n", input);
        }
        while( strcmp( input , "quit" ) != 0 );
}
```


Example from Last Lecture *(cont.)*

```
void inthandler(int s)
{
        printf(" Received signal %d .. waiting\n", s );
        sleep(2);
        printf("  Leaving inthandler \n");
}

void quithandler(int s)
{
        printf(" Received signal %d .. waiting\n", s );
        sleep(3);
        printf("  Leaving quithandler \n");
}
```


Ignore other Interrupts inside Handler?

```
void quithandler(int s)
{
        printf(" Received signal %d .. waiting\n", s );
        sleep(3);
        printf("  Leaving quithandler \n");
}

void inthandler(int s)
{
        signal(SIGQUIT, SIG_IGN);
        printf(" Received signal %d .. waiting\n", s );
        sleep(2);
        printf("  Leaving inthandler \n");
        signal( SIGQUIT, quithandler );
}
```

sigaction() Function

- The *sigaction()* function allows the calling process to examine and/or specify the action to be associated with a specific signal.

```
int sigaction(int sig,
  struct sigaction *new_act,
  struct sigaction *old_act);
```


sigaction() Function *(cont.)*

- This function is "newer" than `signal`, and provides considerably more flexibility.
- Like `signal`, the first argument is a signal number (or name).
- The second argument is a pointer to a structure containing the new characteristics for the signal; the third argument points to a structure which will receive the old characteristics of the signal. Either or both of these pointers may be `NULL`, allowing any combination of setting or querying the action associated with a signal.

sigaction Structure

- `struct sigaction` has the following members:
  - `sa_handler` – set to `SIG_DFL`, `SIG_IGN`, or pointer to handler function (compare this with the second argument to `signal`).
  - `sa_mask` – a set of additional signals to be blocked during execution of the function identified by `sa_handler`.
  - `sa_flags` – special flags that affect the signal behavior.
  - `sa_sigaction` (used only for POSIX real-time signals).

```
struct sigaction {
        void (*sa_handler)(int);
        void (*sa_sigaction)(int, siginfo_t *, void *);
        sigset_t sa_mask;
        int sa_flags;
        void (*sa_restorer)(void);
    }
```


sa_flags

SA_NOCLDSTOP: If signum is SIGCHLD, do not receive notification when child processes stop.

SA_NOCLDWAIT: If signum is SIGCHLD, do not transform children into zombies when they terminate.

SA_RESETHAND: Restore the signal action to the default state once the signal handler has been called.

SA_ONSTACK: Call the signal handler on an alternate signal stack provided by sigaltstack(2).

SA_RESTART: Provide behaviour compatible with BSD signal semantics. by making certain system calls restartable across signals.

SA_NODEFER: Do not prevent the signal from being received from within its own signal handler.

SA_SIGINFO: The signal handler takes 3 arguments, not one. In this case, sa_sigaction should be set instead of sa_handler.

sigaction() *(cont.)*

- A new signal mask is calculated and installed only for the duration of the signal-catching function, which includes the signal being delivered.
- Once an action is installed for a specific signal, it remains installed until another action is explicitly requested.

sigaction() Example

```
main()
{
        struct sigaction newhandler;
        sigset_t         blocked;
        void             inthandler();
        char             x[INPUTLEN];

        newhandler.sa_handler = inthandler;
        newhandler.sa_flags = SA_RESETHAND | SA_RESTART;

        sigemptyset(&blocked);
        sigaddset(&blocked, SIGQUIT);
        newhandler.sa_mask = blocked;

        if ( sigaction(SIGINT, &newhandler, NULL) == -1 )
                perror("sigaction");
        else
                while( 1 ){
                        fgets(x, INPUTLEN, stdin);
                        printf("input: %s", x);
                }
}
```

Masking Signals - Avoid Race Conditions

- The occurrence of a second signal while the signal handler function executes.
  - The second signal can be of different type than the one being handled, or even of the same type.
- The system also contains some features that will allow us to block signals from being processed.
  - A global context which affects all signal handlers, or a per-signal type context.

Masking Signals *(cont.)*

- Each process maintains a signal mask which controls which signals are immediately delivered to the process and which have delivery deferred.
- If a signal is in the signal mask, it is said to be *blocked*.
- The signal mask for a process is initially empty, which means any signal can be delivered.
- Some signals (in particular, `SIGKILL` and `SIGSTOP`) cannot be deferred. Including them in a signal mask is not an error, but will not be effective.
- Blocking a signal is a temporary measure; don't confuse it with ignoring (with `SIG_IGN`) a signal.

sigprocmask() Function

- The system call allows to specify a set of signals to block, and returns the list of signals that were previously blocked.

```
sigprocmask(int how, const sigset_t *set,
    sigset_t *oldset)
```

1. `int how`:
   - Add (`SIG_BLOCK`)
   - Delete (`SIG_UNBLOCK`)
   - Set (`SIG_SETMASK`).
2. `const sigset_t *set`:
   - The set of signals.
3. `sigset_t *oldse`:
   - If this parameter is not `NULL`, then it'll contain the previous mask.

Suspending Masked Signals

sigsuspend(newmask)

- This function blocks the calling process until one of the signals not masked in `newmask` is delivered to the process.
- When invoked, it sets the process signal mask to `newmask` and blocks.
- When an unmasked signal arrives, its handler is invoked.
- Then `sigsuspend` returns, always with a value of `-1` and `errno` = `EINTR`.

Manipulating Signal Sets

The `sa_mask` component of the `sigaction` structure contains a set of signals. This set is modified using the following functions (or macros):

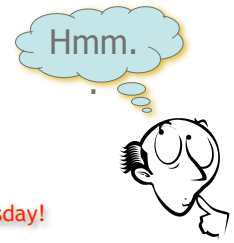
- `sigemptyset (sigset_t *set);` -- init to no signals
- `sigfillset (sigset_t *set);` -- init to all signals
- `sigaddset (sigset_t *set, int signo);` -- add signal
- `sigdelset (sigset_t *set, int signo);` -- remove signal
- `sigismember (sigset_t *set, int signo);` -- check signal

Real-time Signals

- POSIX.4 adds some additional signal facilities. The key features are:
  - The real-time signals are in addition to the existing signals, and are in the range `SIGRTMIN` to `SIGRTMAX`.
  - Real-time signals are queued, not just registered (as is done for non real-time signals).
  - The source of a real-time signal (`kill`, `sigqueue`, asynchronous I/O completion, timer expiration, etc.) is indicated when the signal is delivered.
  - A data value can be delivered with the signal.

Summary

- Signals
  - Generating & Catching Signals
  - Overlapping Signals
  - Preventing Race Conditions
  - Masking Signals



HW 2 out today, due Oct 14th, Tuesday!

Acknowledgments

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